

**Distributed Allocation Of System Hardware Resources  
For Multiprocessor Systems**

**Cross-Reference to Related Applications**

5       The following patent applications, all assigned to the assignee of this application, describe related aspects of the arrangement and operation of multiprocessor computer systems according to this invention or its preferred embodiment.

10       U.S. patent application serial number \_\_/\_\_,\_\_ by T. B. Berg et al. (BEA919990003US1) entitled "Method And Apparatus For Increasing Requestor Throughput By Using Data Available Withholding" was filed on January \_\_, 2002.

      U.S. patent application serial number \_\_/\_\_,\_\_ by T. B. Berg et al. (BEA920000017US1) entitled "Method And Apparatus For Using Global Snooping To Provide Cache Coherence To Distributed Computer Nodes In A Single Coherent System" was filed on January \_\_, 2002.

15       U.S. patent application serial number \_\_/\_\_,\_\_ by T. B. Berg et al. (BEA920000018US1) entitled "Multi-level Classification Method For Transaction Address Conflicts For Ensuring Efficient Ordering In A Two-level Snoopy Cache Architecture" was filed on January \_\_, 2002.

      U.S. patent application serial number \_\_/\_\_,\_\_ by S.G. Lloyd et al. (BEA920000019US1) entitled "Transaction Redirection Mechanism For Handling Late Specification Changes And Design Errors" was filed on January \_\_, 2002.

20       U.S. patent application serial number \_\_/\_\_,\_\_ by T. B. Berg et al. (BEA920000020US1) entitled "Method And Apparatus For Multi-path Data Storage And Retrieval" was filed on January \_\_, 2002.

25       U.S. patent application serial number \_\_/\_\_,\_\_ by W. A. Downer et al. (BEA920000021US1) entitled "Hardware Support For Partitioning A Multiprocessor System To Allow Distinct Operating Systems" was filed on January \_\_, 2002.

      U.S. patent application serial number \_\_/\_\_,\_\_ by W. A. Downer et al.

BEA92000022US1

(BEA920010030US1) entitled "Masterless Building Block Binding To Partitions" was filed on January \_\_, 2002.

U.S. patent application serial number \_\_/\_\_, by W. A. Downer et al.

(BEA920010031US1) entitled "Building Block Removal From Partitions" was filed on January \_\_, 2002.

U.S. patent application serial number \_\_/\_\_, by W. A. Downer et al.

(BEA920010041US1) entitled "Masterless Building Block Binding To Partitions Using Identifiers And Indicators" was filed on January \_\_, 2002.

## **Background Of The Invention**

### **Technical Field**

The present invention relates to a method for use in a multiprocessor, multi-node computer system which utilizes distributed memory located in various nodes when such nodes are interconnected through a communications pathway such as a crossbar device which keeps track of data transaction identifiers. The disclosure relates to a method of allocating hardware resources in a computer system by distributing the responsibility of allocating these resources across various components in the system to improve processing speed and reduce system latency.

### **Description Of The Related Art**

In the past, multiprocessor computer systems utilizing groups of coordinated processing systems and distributed system resources have used hardware devices to communicate between groups of processors in a single system. Such computer systems frequently group one or more microprocessor systems along with memory, input/output controllers and other devices which are local to such processors acting as a single subsystem. Such processor subsystems are frequently coupled together through hardware devices acting as communications pathways, sometimes referred to as crossbars,

which allow communications between the groups of processors allowing access to each group's memory by other groups of processors.

In such systems, it is necessary to provide information through the communications pathway so that other groups of processors may know the availability of resources available to it remotely in other nodes of the system. The related art demonstrates various methods used at controlling access to resources allocating "credit based flow control" throughout a distributed system.

Patent number 5,630,134 issued to Haga finds a central control apparatus which provides exclusive control to processors over specific memory locations within a shared memory region. Haga is directed at controlling access to certain memory spaces and does not anticipate management of hardware resources where such resources managed are not memory regions themselves but rather resources needed to access any arbitrary memory location. The Haga disclosure does not teach management of the resources needed to access memory contents across the system.

Patent 5,027,271 issued to Curley, et al., teaches the use of an apparatus which addresses partitioning and management of system resources such as storage, terminals, and memory. The Curley patent teaches the use of system resources that are controlled and managed by the operating system software, as opposed to a method for use of hardware to allocate memory resources for use across the system.

Patent 4,980,822 issued to Brantley, Jr., et al., discloses a multiprocessing system having nodes containing processors and associated memory modules with dynamically allocated storage across the entire system. The Brantley disclosure teaches a method whereby the virtual memory page table entries are constructed in such a way as to assign the location of such pages of global memory that are to be used by the processor at hand as local pages of memory. The patent also teaches a method which allows interleaving sequential accesses. The present invention does not provide for manipulating page tables to achieve the method provided.

Patent 5,161,227 issued to Dias, et al., discloses a multiprocessor computer system which defines a method for optimizing exclusive control of specific memory locations shared as

synchronization flags in the system. In this patent, memory locations managed by the invention are identified by software and a locking mechanism is specifically invoked with software intervention. The present invention does not require software intervention and does not utilize the method taught in Dias. Furthermore, the present invention's resource management method does not relate to memory locations, but rather to resources that support the access of a memory location when such resources are not visible to the operating software.

Patent 5,974,456 issued to Naghshineh, et al., teaches a method for controlling the flow of input and output requests provided from multiple processors in a system to a given input/output device or input/output bus. The present invention is not limited to input/output requests within the system and is not invoked by operating system software or user programs operating on the system. Further, the method disclosed in the present invention does not affect the requested data in the system, but only the resources used to access data within the system.

Patent 5,930,484 issued to Tran, et al., defines a system that uses dynamically variable width buses to process multiple requests onto a wide system bus shared by multiple processors. This patent teaches optimizing bus band width wherein the present invention defines a centralized method of allocating buffer space for the working space of an issued request within the system, and does not attempt to pack multiple data items together on a dynamically resized system bus.

Patent 5,371,897 issued to Brown, et al., teaches a method of furnishing unique worldwide identifiers to an input/output subsystem so as to support configuration of the input/output devices after a fault within the system. Although Brown teaches use of node identifiers locally, the present invention does not bear on the subject of providing unique node identifiers on a global basis throughout the system.

Patent 4,956,771 issued to Neustaedter, teaches a method of managing data buffers for an input/output controller device. The method in this referenced patent requires an extensive amount of software support in both the operating system and the input/output controller device to operate. The method taught in the present invention is independent of software and does not require the participation

of input/output device controllers in order for the method to operate.

While management of memory resources across a distributed processing system have been addressed in various aspects by the patents set forth above and other disclosures, none have taught a method whereby one system component can be assigned the responsibility of allocating resources on a second system component when such first component is supplying the resource consuming operations. Credit based system resource management methods, as used in the past, do not provide for obtaining additional hardware resource information useful in managing and applying system resources as they apply to distributed systems throughout a multiprocessor computer system.

### Summary Of The Invention

A first aspect of the invention is a method for handling resources of a multiprocessor system in which a requestor group of one or more processors of the system is interconnected to a target group of one or more processors of the system. In the method, the requestor allocates a resource of the target, the resource being associated with a request of the requestor. The requestor then sends a result of the request to the target, and the target directly receives the result using the resource without intermediate handling of the resource. The requestor and the target are preferably but not necessarily interconnected by a central hardware device, such that the requestor allocates the resource by sending a request to the central hardware device which then allocates the resource at the target group.

A second aspect of the invention is a computing system having interconnected requestor and target groups of one or more processors each. A resource allocator receives and responds to requests of the requestor. The target is responsive to both a resource provided by the resource allocator and a result of the request from the requestor. The target directly receives the result responsive to the resource without intermediate handling of the resource by the target. The system preferably interconnects the requestor and the target using a central hardware device which includes the resource allocator, although the requestor can alternatively be interconnected directly.

### Brief Description Of The Drawings

**Fig. 1** is a block diagram of a four quad multiprocessor system including a tag and address crossbar system according to the preferred embodiment of the invention.

**Figs. 2A-2C** are a block diagram of the tag and address crossbar system of Fig. 1. Fig. 2B is suggested for printing on the first page of the issued patent.

**Fig. 3** is a flowchart showing the operation of the TrID allocator of Fig. 2.

### Detailed Description Of The Preferred Embodiment

#### Overview

In multiprocessor computer systems comprised of more than one processing node, hardware resources such as temporary data buffers must be allocated dynamically. In the preferred embodiment, resources required to complete a transaction within a memory controller are identified as a transaction identifier (TrID). In the preferred embodiment, the allocating component is a communications pathway consisting of a tag and address crossbar system which allocates TrID resources that exist on the target components known as memory control agents. Each node of the multiprocessor system disclosed has a memory control agent which coordinates one or more processors in the node along with local system resources and communications with the crossbar system. The tag and address crossbar alone issues requests that cause the transaction identifiers (TrIDs) corresponding to resources inside the memory control agent to be allocated. When the memory control agent has completed work on the transaction, the memory control agent then deallocates the resources consumed by that transaction by using its interconnection with the crossbar. Data flow control and allocation of TrIDs are performed in advance and without time latency cost.

The allocating component in the system makes a request of a target component which includes information about the identification of the source node of the request and the source transaction unit object as well as the target node identification and the target transaction unit object. By transmitting this

information in a data request initially to a target node, data transmission between the source and the target or back from the target to the source can be accomplished without further intervention by the component allocating the transaction unit object.

5 The TrID and resource handling method of the preferred embodiment first has the source node send a request (such as for a read or write of data) to the central device or crossbar communications pathway. The central device allocates the resources for any transactions that are required to complete that request, and assigns a TrID for the request. The central device responds back to the memory control agent of the source node indicating what action it needs to take, such as sending or receiving data across the data crossbar. The source node then sends the results to the target, which receives the results directly into the resource. In the case of a read request, the target node receives the original requestor's TrID and thereby knows where to send the data which the source node requested be read by the target.

### Technical Background

15 The method of the preferred embodiment is used in a multiple processor system, configured in two or more independent processing nodes, which utilizes a tag and address crossbar system for use in combination with a data crossbar system, together comprising a data processing system to process multiple data read and write requests across the nodes. Typical multiprocessor systems utilize a communications pathway by implementation of one or more hardware devices which interconnect various groups of multiprocessors associated with memory which is local to such processors. Multiple processor groups are interconnected through such pathways utilizing systems known as tag and address crossbars and data crossbars, all acting together to allow the multiple processor subsystems to operate in a coordinated fashion. Such coordination is ordinarily accomplished by interconnection of the crossbar systems with a memory controller associated with each separate group of processors such that the crossbar communications pathway essentially interconnects such memory control systems.

25 Memory control systems allow the processors from any node in the system to utilize memory local to it

or memory local to other nodes which would, by definition, be remote to a processor not in such other node. Therefore, memory control systems in each processor node must interact through the crossbar system to allocate resources within the memory controller and otherwise communicate requests for data from other nodes and satisfy such requests.

5 In allocating hardware resources dynamically, the communications necessary to maintain the allocation can become problematic in terms of time by increased system latency, and additional cost for additional component count in coordinating data communications. Resources within a component such as a memory system are often allocated by that component itself, which requires adding communication paths between the components operating in a system to arbitrate for resources and the control of the flow of data so that data transmissions through the system do not exceed the amount of resources available at any time.

10 In order to reduce the system overhead in terms of latency and component requirement, a first system component can be assigned the responsibility of allocating resources of a second component, the target, when the first component is supplying the resource consuming operations such as memory reads or writes. One or more memory control agents may communicate between each other through the interconnecting crossbar. In the case where the target component is deallocating a resource, such as an internal buffer associated with a memory line, communication is still required so that the first component can observe the deallocations and thereby target the deallocated resource for immediate reuse. Allocation by the first component and deallocation by the target component has the desirable feature that the allocation latency is minimized, thereby increasing performance of the system.

### Technical Details

25 **Fig. 1** presents an example of a typical multiprocessor systems in which the present invention may be used. **Fig. 1** illustrates a multi-processor system which utilizes four separate central control systems (control agents) 66, each of which provides input/output interfacing and memory control for an array 64 of four *Intel* brand *Itanium* class microprocessors 62 per control agent 66. In many



applications, control agent 66 is an application specific integrated circuit (ASIC) which is developed for a particular system application to provide the interfacing for each microprocessors bus 76, each memory 68 associated with a given control agent 66, PCI interface bus 21, and PCI input/output interface 80, along with the associated PCI bus 74 which connects to various PCI devices.

Fig. 1 also illustrates the port connection between the tag and address crossbar 70 as well as data crossbar 72. As can be appreciated from the block diagram shown in Fig. 1, crossbar 70 and crossbar 72 allow communications between each control agent 66, such that addressing information and memory line and write information can be communicated across the entire multiprocessor system 60. Such memory addressing system is necessary to communicate data locations across the system, and to facilitate update of cache information located in the crossbars 70 and 72 regarding data validity and data locations.

A single quad processor group 58 is comprised of microprocessors 62, memory 68, and control agent 66. In multiprocessor systems to which the present invention relates, quad memory 68 is usually Random Access Memory (RAM) available to the local control agent 66 as local or home memory. A particular memory 68 is attached to a particular controller agent 66 in the entire system 60, but is considered remote memory when accessed by another quad or control agent 66 not directly connected to a particular memory 68 associated with a particular control agent 66. A microprocessor 62 existing in any one quad processor group 58 may access memory 68 on any other quad processor group 58. NUMA systems typically partition memory 68 into local memory and remote memory for access by other quads.

Every port of tag and address crossbar 70 is assigned to one of four control agents 66 by virtue of its physical connection between agent 66 and crossbar 70. Interconnections between tag and address crossbar 70 and data crossbar 72 to each of control agents 66 are accomplished through bus 71. Shown in Fig. 1 as a connection from tag and address crossbar 70 and data crossbar 72 to the control agent 66 in quad one, the bus is also referred to as a port. Though shown only at quad one, the configuration of bus 71 is duplicated for each quads 58 as can be appreciated by the connections for

ports 0, 1, 2 and 3 shown in **Fig. 1**. Bus 73 is the portion of bus 71 that connects control agent 66 to tag and address crossbar 70. Bus 75 is the portion of bus 71 which connects the data crossbar 72 to each control agent 66. Each of the quads of the system demonstrated in **Fig. 1**, communicate to the remaining portions of the system through tag and address crossbar 70 as well as data crossbar 72 through channels defined as ports. Ports 0, 1, 2 and 3 are all shown on **Fig. 1** interconnecting the crossbar systems with each quad's control agent 66. All of the processor groups or quads 58 in **Fig. 1** are connected in a similar fashion, as can be appreciated from the figure, utilizing interconnect bus 71 as shown in port 1 of **Fig. 1**. The crossbar systems, including the ports interconnecting the crossbars with each of the quads 58, are essentially a communication pathway connecting the processing nodes so that they may all share access to data stored throughout the system. Crossbar 70 provides a reply to any new requests for a data operation from any of the control agents 66. Such additional information which is tracked includes the transaction identification (TrID) on the source node for the transaction; the transaction type; whether the data is a full cache line or just a partial line of data; and if the operation involves a partial line of data, which part of the cache line to which the data is associated.

In most multiprocessor systems which utilize distributed system memory, each group of multiprocessor's acting as a single group, node, or quad as referenced in the preferred embodiment, control agent 66 must manage transactions throughout the system to assure that a request for data or other transaction within the system is directed to or communicated to the proper system node, utilizing the memory space desired. Considering **Fig.1**, if control agent 66 in quad 1 receives a write request from one of its processors 62, each control agent 66 has a grouping of TrIDs it may assign to the request to keep track of the request within its system. Each control agent 66 communicates with tag and address crossbar 70 so that tag and address crossbar 70 may interact with the request. In the example using **Fig.1**, a write request from agent 66 in quad 1 will be communicated to tag and address crossbar 70. In a particular instance, tag and address crossbar 70 will have stored within its tag memory the location to which control agent 66 in quad 1 must write that particular data. If the data should be written to memory 68 in quad 2, for example, tag and address crossbar 70 will communicate

that information to control agent **66** in quad 1.

Tag and address crossbar **70** will assign a TrID corresponding to the resource in the target quad, in this example quad 2, and communicate that TrID back to the control agent **66** in quad 1. Control agent **66** will attach this TrID to the data corresponding to that write operation. Accordingly, a subsequent operation from control agent **66** in quad 1 can be the communication of the data which has been tagged with the TrID assigned by tag and address crossbar **70** directly to the other control agent **66** to which the data should be sent, in the example agent **66** of quad 2 in **Fig. 1**. However, the invention provides that the data and associated TrID moves to the target location by communications through the data crossbar **72**.

**Fig. 2** (shown in multiple parts as **Figs. 2A-2C** for clarity but representing a single diagram) illustrates internal logic of tag and address crossbar **70** shown in **Fig. 1**. Input **40** for port 0, input **41** for port 1, input **42** for port 2, and input **43** for port 3 illustrate part of the communications pathway connections each control agent **66** in each quad or node into tag and address crossbar **70**. Likewise, **Fig. 2** illustrates port 0 output **45**, port 1 output **46**, port 2 output **47** and port 3 output **48**, each said output also illustrated on the entire system block diagram shown in **Fig. 1**. Tag memories which function with tag and address crossbar **70** are shown at **81(a)** and **81(b)**. Registers **81(a)** and **81(b)** are identical except that they are associated with an even pipeline and odd pipeline for tag processing. The dual pipeline design is provided to reduce latency in the system by assigning processing to even numbered cache line addresses to the even pipeline and odd numbered cache line addresses to the odd pipeline so that simultaneous processing may occur.

Continuing with **Fig. 2**, input **40**, **41**, **42** and **43** are each introduced through a buffer, and through a split are operatively connected to even input multiplexor **50**, and odd input multiplexor **51**, the appropriate multiplexor (mux) being selected in accordance with the even or odd relationship with the input address. Each multiplexor **50** and **51** serves to serialize the flow of tags from the four inputs. The outputs of multiplexor **50** and **51** are sent to another multiplexor to be sent ultimately to tag memories **81(a)** and **81(b)**. Even pipeline logic **52** and odd pipeline logic **53** evaluates the tags being presented

and the request type to generate an output response and requests to the appropriate ports. The resulting output entries are buffered in the dispatch buffer **54** and **55**, each of which is a first in, first out (FIFO) type buffer. Dispatch buffers **54** and **55** decouples timing variances between the tag logic shown and the output selection logic. Entries are stored in dispatch buffers **54** and **55** in first in, first out order until they can be sent to the destination ports, being output **45**, **46**, **47** or **48**, representing one output to each port or quad.

A TrID allocator **57** is responsible for managing TrIDs tag and address crossbar **70** makes available for outbound transactions. There is one TrID allocator **57** for each tag and address crossbar **70** Port. Each TrID allocator **57** manages sixteen TrIDs.

TrIDs managed by the TrID allocator **57** can be allocated and released. When allocating TrIDs, each of the TrID allocator **57** supplies TrIDs to both the even pipeline logic **52** and odd pipeline logic **53**. TrIDs are allocated due to the generation of outbound transactions by the dispatcher **84**, **85**. Since there are two pipelines as shown in **Fig. 2**, each of the TrID allocators **57** can allocate up to four TrIDs per cycle.

The TrIDs managed by the TrID allocators **57** correspond to a set of resources in the control agent **66** attached to the same port. When all sixteen TrIDs are allocated, the control agent **66** has no more resources to support outbound tag and address crossbar **70** transactions. The dispatch buffer inhibits sending outbound transactions when TrIDs are unavailable, so flow control between tag and address crossbar **70** outbound transactions and the control agent **66** is based on TrID availability.

The control agent **66** can direct the TrID allocator **57** to release a TrID when it has completed using the resources associated with that TrID. To do so the control agent specifies which TrID is being deallocated. Such releases are routed from bus input logic communicating with input **40**, **41**, **42** and **43** for each port to the TrID allocator **57** for that port. A TrID allocator **57** can receive one TrID release per clock cycle.

The TrID allocator **57** contains a 16-bit register to keep track of which TrID's are available. After reset, all TrID's are made available to the TrID's allocator **57**. The allocation of TrID's can be

disabled by the TrIDDis vector. The TrIDDis vector is comprised of the TrID mask bits to selectively enable or disable a TrID. The TrIDDis vector may be set by a control status register (CSR) access and is used to mask certain TrID's from the available pool of sixteen TrID's. A MMIONumTrIDs signal represents the maximum number of Memory Mapped Input/Output (MMIO) TrIDs permitted. MMIONumTrIDs is also set by a CSR access to control the number of TrID's that may be allocated for MMIO transactions. The TrID allocator 57 keeps track of the number of currently allocated MMIO TrID's at any given time. If this number is greater than the MMIONumTrIDs value, MMIO requests will not be allowed to consume any more TrIDs. This function is necessary in order to prevent the case where MMIO requests consume all TrIDs and cause a deadlock condition to occur. A deadlock condition can occur in the system when multiple MMIO requests allocate all available target TrIDs. The MMIO TrIDs are thus resources which control the ability of a target control agent 66 to satisfy a memory mapped I/O transaction requested by another control agent.

TrID #15 is dedicated for a special transaction type called TLB Purge (TLBP). A dedicated TrID is required due to protocol restrictions. The operating system ensures that there is only one ongoing TLB Purge transaction at any one time. Thus, only one TrID needs to be reserved for a TLBP operation. Thus, TrID #15 is a resource which controls the ability of a target control agent 66 to satisfy a TLB Purge transaction requested by another control agent.

The dispatch buffer informs the TrID allocator 57 how many TrIDs are required for a given transaction.

Similar signals are sent from the TrID allocator 57 to the dispatch buffers to indicate what TrIDs are available. The TrID allocator 57 will always attempt to supply up to four distinct TrIDs (two per pipe line). The TrID allocator 57 does not know in advance whether a dispatcher needs MMIO or Cacheable TrIDs, so it makes both available. To do this, the TrID allocator 57 will report that two cacheable TrIDs and one MMIO TrID are available per pipeline. However, the dispatch buffer will take either cacheable or MMIO TrID, but not both. Because of this, the same TrID is made available as both a cacheable and a MMIO TrID.

As shown in **Fig. 3**, TrID allocation as performed by TrID allocator **57** begins when the TrID allocator receives a TrID allocation request from one of the control agents **66** (step **91**). TrIDs are selected by scanning a sixteen bit TrID vector for available TrIDs (step **92**). TrID #15 is reserved for TLBP transactions, and the other TrIDs may be disabled from selection by the CSR logic. The vector is scanned in descending order. The last TrIDs found (up to four) are passed to TrID arbitration logic (step **93**), and the TrIDs resulting from the arbitration are distributed to the even and odd dispatch buffers (step **94**). The selection logic provides up to four TrIDs. However, when TrIDs start being consumed and fewer are available to the point where four cannot be allocated, an arbitration scheme is used (step **93**) so that the even or odd pipeline will be given a fair chance to obtain the necessary TrIDs. This arbitration is accomplished with a fairness bit that indicates whether the even or odd pipeline should win the allocation. The fairness bit is flipped each time a dispatch buffer takes a TrID.

In Table 1 below, the number of TrIDs found by the TrID allocator **57** are represented by the four-bit Found vector, which is preferably encoded one-hot. The corresponding TrID ID numbers are held in a sixteen-bit FoundTrIDs vector (four bits per ID). The TrIDAvailable signals (labeled in Table 1 as TrIDAvail and as even or odd, and even MMIO or odd MMIO) indicate the number and type of TrIDs being made available to the even and odd dispatch buffers **54** and **55** (step **94**).

**Table 1****TrID Available Truth Table**

Found	Fairness Bit	EvenTrIDAvail	OddTrIDAvail	EvenMMIOTrIDAvail	OddMMIOTrIDAvail
0000	Even	00	00	0	0
0000	Odd	00	00	0	0
0001	Even	01	00	1	0
0001	Odd	00	01	0	1
0011	Even	11	00	1	0
0011	Odd	00	11	0	1
0111	Even	11	01	1	1
0111	Odd	01	11	1	1
1111	Even	11	11	1	1
1111	Odd	11	11	1	1

The MMIO TrID will only be made available if the number of MMIO TrID already allocated is smaller than the maximum value specified by the CSR logic. It is possible to allocate one more MMIO TrID than the maximum value in the event that the number currently allocated is one less than maximum and the even and odd pipes both take an MMIO TrID simultaneously. An optimization is performed in the event that enough TrIDs are not available for one pipeline, and the other pipeline is being offered TrIDs that it does not need. In this case, the fairness bit is flipped. In the next clock cycle, the pipeline requiring the TrID will be satisfied.

TrID numbers are extracted from the FoundTrIDs vector shown in Table 2 and passed to dispatch buffer **54** or **55** (step **941**), depending on whether the even or odd pipeline. One TrID number is sent for every TrID made available. The FIRSTTrID, SECONDTrID, MMIOTrID are signals sent from the TrID allocator **57** to the dispatch buffer. Table 2 below shows how TrIDs are selected for the even and odd dispatch buffers **54** and **55**, respectively.

**Table 2**  
**TrID Selection**

Found	Fairness Bit	EFIRSTTrID (Even first TrID)	ESECONDTrID (Even secondTrID)	EMMIOTrID (Even MMIO TrID)	OFIRSTTrID ((Odd first TrID)	OSECONDTrID (Odd secondTrID)	OMMIOTrID (Odd MMIO TrID)
0000	Even	0000	0000	0000	0000	0000	0000
0000	Odd	0000	0000	0000	0000	0000	0000
0001	Even	FoundTrIDs[3:0]	0000	FoundTrIDs[3:0]	0000	0000	0000
0001	Odd	0000	0000	0000	FoundTrIDs[3:0]	0000	FoundTrIDs[3:0]
0011	Even	FoundTrIDs[3:0]	FoundTrIDs[7:4]	FoundTrIDs[3:0]	0000	0000	0000
0011	Odd	0000	0000	0000	FoundTrIDs[3:0]	FoundTrIDs[7:4]	FoundTrIDs[3:0]
0111	Even	FoundTrIDs[3:0]	FoundTrIDs[7:4]	FoundTrIDs[3:0]	FoundTrIDs[11:8]	0000	FoundTrIDs[11:8]
0111	Odd	FoundTrIDs[3:0]	0000	FoundTrIDs[3:0]	FoundTrIDs[11:8]	FoundTrIDs[7:4]	FoundTrIDs[11:8]
1111	Even	FoundTrIDs[3:0]	FoundTrIDs[7:4]	FoundTrIDs[3:0]	FoundTrIDs[11:8]	FoundTrIDs[15:12]	FoundTrIDs[11:8]
1111	Odd	FoundTrIDs[3:0]	FoundTrIDs[7:4]	FoundTrIDs[3:0]	FoundTrIDs[11:8]	FoundTrIDs[15:12]	FoundTrIDs[11:8]

TrIDs selected and arbitrated remain available until they are used by the dispatch buffer. The dispatch buffer informs the TrID allocator **57** how many TrIDs of what type were taken (step **95**). The TrID allocator **57** then updates its vector of available TrIDs in the next clock cycle (step **96**). If the

dispatch buffer has taken only one cacheable TrID, it is assumed that the TrID associated with FirstTrID was taken.

Control agent 66 releases a TrID by sending a control signal along with the TrID of the TrID to be released to the tag and address crossbar 70. These signals are forwarded to the TrID allocator 57 by the input logic on each input bus of tag and address crossbar 70, being input 40, 41, 42 and 43. The TrID allocator 57 receives these signals (step 97) and updates its vector of available TrIDs in the next clock cycle (step 98).

### Advantages

The tag and address crossbar 70 allows the control agent 66 of a requestor quad 58 to initiate a transaction requiring allocation of a TrID needed by the control agent of another, target quad for processing the transaction. The requestor quad can send the transaction to the target quad(s) without further action by the target quad(s), and the target quad(s) can receive the transaction directly using the TrID allocated by the requestor quad, without further buffering or other intervention, thereby reducing the latency of the transaction and increasing the performance of the system.

### Alternatives

The preferred embodiment of the invention as shown and described in detail is fully capable of obtaining the objectives of the invention. However, it should be understood that the described embodiment is merely an example of the present invention, and as such, is representative of subject matter which is broadly contemplated by the present invention.

While the invention is most beneficial in a system having central control device or system to communicate between nodes, and has been described as embodied in a system having tag and address crossbar and data crossbar systems which interconnect groups of processors employing non-uniform memory access or distributed memory across the system, the invention can be employed in any multiprocessor system having groups of one or more processors which exchange requests for



resources, including those having no central device but which instead are directly interconnected to each other.

Further, while the preferred embodiment as described above utilizes sixteen microprocessors, comprised of four separate groups or quads of four processors each, with each quad having a memory control agent which interfaces with the central controller via crossbars, having memory boards allocated to the quad and for which the preferred embodiment functions to communicate through other subsystems to like controllers in the other quads, nevertheless the present invention may be used with any system having multiple processors, whether grouped into "nodes" or not, with separate memory control agents assigned to control each separate group of one or more processors when such group of processors requires coordination in handling the allocation of hardware resources for data transactions within a multi-node system. The present invention is there not limited to the specific numbers or arrangements of processors, or to the specific interconnect, described in the preferred embodiment.

Accordingly, the scope of the present invention fully encompasses other embodiments which may become apparent to those skilled in the art, and is limited only by the following claims.